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Measuring disaster resilience in MENA countries and its impact on disaster losses

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Disaster resilience is a protective feature aimed at reducing the effects of natural disaster events and losses resulting from these events. This study develops a Disaster Resilience Index (DRI) for MENA countries to assess resilience across ten dimensions, including economic, social, institutional, infrastructural, and environmental factors. Unlike most prior studies, which focus on individual countries or use narrower sets of indicators, this study provides a multi-country, region-specific framework tailored to MENA's socio-economic and environmental heterogeneity. The index integrates geospatial data on disaster risk from geographic information systems (GIS) and a natural hazard risk dimension. Validation using disaster-related fatalities, supported by a dual PCA-based sensitivity analysis, confirms the robustness of the DRI and reveals that countries with stronger governance, higher human capital, and robust infrastructure tend to exhibit greater resilience, while fragile states and resource-dependent economies are more vulnerable. Notably, the DRI calculated using both dimension-specific and all-indicator PCA produces closely aligned values, indicating the choice of conducting PCA at the dimension level does not significantly alter the overall assessment of disaster resilience. These insights provide a foundation for targeted disaster risk reduction strategies and highlight areas where international cooperation and policy interventions can strengthen resilience in the region.

Keywords Disaster resilience index, MENA, Disaster losses, Natural hazards, Principal component analysis (PCA)

Since the beginning of human existence, disasters have posed a significant threat, causing harm and damage to both individuals and their belongings. The frequency and intensity of natural disasters have dramatically increased because of climate change. Over the past two decades, the world has suffered approximately three trillion dollars in losses due to 7,000 natural disasters[1].

Disaster resilience is a protective feature aimed at reducing the impacts of natural disasters and losses resulting from these events. Disaster resilience results as a consequence of the capacity of social, economic, and government systems to prepare for, respond to, and recover from a natural disaster event, and to learn, adapt, and transform by anticipating future natural disaster events. Transforming societies into a state that is resistant to natural disasters is the fundamental objectives of disaster management. This goal was adopted by 168 countries in the Hyogo Framework for Action (HEF) in 2005 (UNISDR, 2005), which marked an important milestone in global disaster risk reduction efforts.

The United Nations Sendai Framework for Disaster Risk Reduction (2015–2030)[2], which replaced the HEF in 2015, recommends four actions to avoid new disaster risks and condense the disaster risks: understanding disaster risk; improving governance and management of disaster risk; regarding disaster resilience investing in disaster mitigation and boosting disaster preparedness. In other words, the Sendai framework aims to increase disaster resilience and significantly reduce disaster risk and disaster-related losses by integrating environment, socio-economic, health, governance, innovation and technology fields in the next 15 years[3,4]. On the other hand, Sustainable Development Goal 13 is on disaster risk reduction strategies. Together, these international frameworks provide a critical foundation for assessing and improving resilience at national and regional levels[5,6].

In parallel to this framework, the aim of this study is to propose a disaster resilience index (DRI) for the MENA countries, to facilitate a more comprehensive understanding of disaster resilience in the region. By capturing the

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multidimensional nature of resilience and adaptive capacity, the DRI will enable policymakers, practitioners, and researchers to assess and monitor the region's preparedness, response, and recovery mechanisms. This, in turn, can inform evidence-based decision-making, aid resource allocation, and foster the development of effective strategies and policies to mitigate the effects of natural disasters and enhance the region's overall resilience.

The MENA region faces a unique and complex profile of disaster vulnerabilities[7,8]. It is exposed to various types of natural hazards—including droughts, floods, earthquakes, and extreme heat events—while simultaneously experiencing rapid urbanization, resource scarcity, and geopolitical instability[9–12]. These challenges make MENA distinct from other disaster-prone regions and underline the importance of a tailored approach. In contrast, Southeast Asia has made significant progress in resilience-building through regional cooperation frameworks (e.g., ASEAN's Agreement on Disaster Management and Emergency Response)[13,14] and investments in advanced early-warning and transboundary disaster systems[15]. Similarly, sub-Saharan Africa, though challenged by poverty and governance constraints, benefits from growing community-based adaptation initiatives[16–18]. These dynamics emphasize the urgent need for a regionally tailored disaster resilience assessment that captures these unique characteristics. Aligning with international frameworks such as the Sendai Framework and SDG 13, this study addresses a critical gap in the literature and provides practical insights for strengthening resilience in one of the world's most hazard-prone yet underrepresented regions.

Most existing DRI frameworks (see Table 1) have been developed and validated in North America and Europe, regions with very different hazard profiles, governance systems, and socio-economic structures. Applying these methods directly to MENA risks dominating critical region-specific factors such as persistent water stress, dust storms, and fragmented disaster governance. Additionally, the dominant hazards in MENA, including prolonged droughts and extreme heat events, are seldom emphasized in indices designed for temperate and highly institutionalized settings. These differences raise concerns about the accuracy and applicability of global frameworks when assessing resilience in the MENA region. This contextual mismatch necessitates a new methodology that incorporates MENA-specific dimensions—such as Geographical Resilience and Natural Hazard Risk—and leverages spatial analytics to account for the region's heterogeneity. This approach ensures that the resulting index is both methodologically robust and practically relevant for policymakers and practitioners in the MENA context.

While some global DRIs[1,19] include multiple countries, MENA's representation remains limited. This study develops a novel, comprehensive DRI designed for MENA, making several contributions: First, it extends the geographic coverage of resilience measurement by including disaster-prone MENA countries that are largely absent in individual country studies and the global studies[1], addressing a significant gap in the global understanding of resilience. Second, it strengthens the conceptual framework of resilience assessment by systematically reviewing existing indicators in the literature and augmenting the dataset of[1] with additional indicators relevant to the socio-economic and institutional contexts of the region. Third, it advances methodological approaches by integrating geospatial data from GIS into the DRI, allowing for the consideration of spatial inequalities and physical accessibility—factors often disregarded in prior studies. Fourth, the inclusion of a natural hazard risk dimension improves the index's ability to account for multi-hazard environments, moving beyond frameworks that assume uniform hazard exposure. Fifth, the study validates the robustness of the DRI by establishing its correlation with disaster-related fatalities and implementing a dual PCA-based sensitivity analysis to assess the stability of the index's results under alternative weighting schemes. Together, these contributions provide a more comprehensive and context-sensitive framework for assessing disaster resilience in MENA countries and offer a foundation for cross-regional comparisons.

Among the highly cited papers in the area,[20] conducted a comprehensive literature review focusing on disaster resilience indices. As[21] demonstrate in their bibliometric analysis of resilience studies, the concept spans multiple disciplines, reflecting its complex and evolving nature in disaster management research. This paper makes a distinctive contribution by introducing an engineering perspective into the realm of social sciences, thereby addressing this identified need for interdisciplinary engagement.

The plan of the study is as follows: The next section discusses the conceptual framework of the disaster resilience index. Sect. "Analysis" explains the methodology and data employed, while Sect. "Results and discussion" elucidates the results. Sect. "Sensitivity analysis" presents the sensitivity analysis. Finally, the last section concludes.

Conceptual Framework

The term disaster resilience is based on the work of[22]. The idea of disaster resilience has multiple definitions in different disciplines in the literature and there is no single generally accepted description[23,24]. Resilience, especially the concept of community resilience, has become a de facto framework for improving disaster preparedness, response and recovery at the community level in the short term and adaptation to climate change in the long term. Although there is no consensus on a precise definition of disaster resilience, there is a common view that disaster resilience improves a community's capability to get ready and plan for, absorb, recover from, and adapt better to natural disasters in a given situation[20].[25] presented a comprehensive conceptual framework and theoretical background to improve deficiencies in vulnerability and resilience models on disaster resilience as well as establish foundations for resilience measurement. They proposed a disaster resilience (DROP) model that integrates discipline-based literature, which is used as the theoretical basis of disaster resilience indices. The DROP model has been widely used to highlight how different dimensions of resilience shape disaster outcomes. In the MENA region, this conceptual lens is particularly relevant, given the complex interplay between socio-economic vulnerabilities, rapid urbanization, and high exposure to multiple hazards such as earthquakes, floods, epidemics, and droughts. For example, infrastructure resilience—through earthquake-resistant buildings, robust transport networks, and flood protection systems—directly moderates fatalities and damage during seismic and hydrometeorological events. Similarly, economic resilience enables recovery by providing financial resources,

Authors	Region	Methodology	Context	Dimension	# ind
Country based studies					
[25]	US	An integration of the literatures	The disaster resilience of place (DROP) model	Ecological, Social, Economic, Institutional, Infrastructure, Community Competence	29
[32]	Two regions of US: Sikeston, Missouri and Carbondale, Illinois	Model construction based on survey data	Disaster preparedness model	Fire Protection, Emergency Medical Services, Public Safety/Police, Planning and Zoning, Emergency Management Office, Other Emergency Functions, Additional Community Measures, Hazard Exposure, Evacuation and Warnings, Community Resiliency	47
[26]	Region IV of US	Indexation using equal weights	Baseline resilience indicators for communities (BRIC)	Social, Economic, Institutional, Infrastructure, Community Capital	36
[33]	US Gulf Coast Counties	Indexation using equal weights	Community disaster resilience index	Social Capital, Economic Capital, Physical Capital, Human Capital	75
[29]	USA	Survey	Social vulnerability index (SVI)	Socioeconomic Status, Household Composition and Disability, Minority Status & Language, Housing & Transportation	15
[20]	US settlements	Indexation using equal weights	BRIC	Social, Economic, Institutional, Infrastructure, Capital, Environment	49
[34]	Korea	Indexation using PCA	Community disaster resilience index	Human, Social, Economic, Environmental, Institutional	24
[30]	Iran	Literature review	Social vulnerability	Gender; Demographic Characteristics, Socio-Economic Conditions, Public Resource Provision, Disability & Special Needs	–
[35]	Italy	Adjusted Mazziotta-Pareto (AMP)	Community disaster resilience index	Services, Cohesion, Economic Resources, Housing Conditions, Education, Environmental Status, Institutions	27
[36]	Norway	Indexation by using equal weighting	Community resilience index	Social, Economic, Institutional, Infrastructure, Capital, Environment	52
[37]	Australia	Indexation by using equal weighting	Australian natural disaster resilience index	Coping Capacity: social character, economic capital, infrastructure and planning, emergency services, community capital, information & engagement. Adaptive Capacity: governance, policy & leadership, social & community engagement	78
[38]	Coastal Communities of the US	Indexation using PCA	Composite Community disaster resilience index	Social, Economic, Community Engagement & Capital, Housing/Infrastructural, Environmental Resilience	25
[39]	China	Indexation using PCA	Regional resilience capacity index	Ecology, Economy, Engineering, Society	28
[40]	New Jersey, US	Pre-determined weights	Community intrinsic resilience index	Transportation, Energy, Health, Socio-Economic Indicators	15
[41]	Australia	In-depth semi-structured interviews	Preparedness competence index	Recognition and Personalisation of Risk, Formal Planning at all Levels, Personal Characteristics of Individuals in Target Communities	–
[31]	USA	Survey and Machine Learning	Disaster preparedness	–	–
[42]	Castilla y Leon, Spain	Indexation using HAS and PCA	Integrated multidimensional resilience index	Social, Economic, Ecosystem, Physical, Institutional, Cultural	191
Multiple country studies					
[1]	91 countries	Indexation using PCA	Natural disasters resilience index	Economic Stability, Emergency Workforce, Agricultural Development, Human Capital, Digitalization, Infrastructure, Governance, Women Empowerment, Social Capital	62
[19]	90 countries	Indexation using PCA	Natural disasters resilience index	Economic Performance, Human Capital, Women Empowerment, Social Capital, Emergency Workforce, Infrastructure, ICT, Institutional Quality, Food & Agriculture	62

Table 1. Literature review. Note: HAS: Hierarchical Segmentation Analysis; PCA: Principal Component Analysis.

insurance mechanisms, and diversification away from climate-sensitive sectors, thereby buffering losses from disasters such as droughts or oil price shocks that exacerbate fiscal stress.

The empirical application of the DROP model was further refined by[26]. The evolution from conceptual framework to measurement is difficult. The major problem is the complexity related to the multifaceted nature of resilience. Most of the evaluation techniques are quantitative based on the choice of indicators as proxies as it is almost impossible to measure absolute resilience[27]. The indicators are selected based on validity, sensitivity, robustness, reproducibility, coverage, usability and others. This approach is criticized in literature due to the subjectivity arising from variable selection and weighting, unavailability of some of the variables, aggregation, and validation issues[28]. Overall, still the quantitative indicators are commonly used due to the various advantages such as decreasing complexity, measuring progress, mapping, and setting priorities. Especially in the MENA context, social resilience, captured by education, social capital, and demographic composition, plays a key role in determining how effectively populations evacuate or access health services during crises such as pandemics or heatwaves. Institutional resilience, reflected in governance quality, disaster management systems, and policy enforcement, moderates the scale of losses by ensuring effective coordination of emergency response, as observed in epidemics and regional conflicts that strain state capacity. Meanwhile, agriculture and environmental resilience directly influence drought-related losses and food insecurity, both of which are recurring challenges in North African and Middle Eastern countries.

The DROP model laid the foundation for the Baseline Resilience Indicators for Communities (BRIC), which provided a conceptually grounded and empirically validated approach that is easily interpretable for policymakers and practitioners. BRIC enabled spatial comparisons across regions and informed decision-making by highlighting disparities in resilience capacity. Specifically, BRIC demonstrated how human capital resilience, including education, health, and workforce skills, reduces disaster impacts by facilitating adaptive recovery and post-disaster labor market stability. Building on this foundation[20], further refined their methodology and evaluated resilience across six dimensions: social, economic, institutional, infrastructure, community capital, and environmental each of which aligns with specific disaster pathways in MENA. For instance, infrastructure resilience mitigates earthquake fatalities, environmental resilience reduces vulnerability to desertification and extreme heat, and institutional resilience ensures effective disaster governance.

As summarized in Table 1, many subsequent studies have relied on these foundational frameworks, adapting their methodologies to reflect country-specific contexts and data availability. Common practices include identifying locally relevant indicators, synthesizing them into composite indices, and employing statistical techniques such as principal component analysis for aggregation and interpretation. While these adaptations demonstrate the versatility of the BRIC framework, they also reveal a geographic concentration of studies in North America, Europe, and Asia, leaving regions such as the MENA underrepresented in empirical resilience research.

In addition to explicit disaster resilience indices, several related frameworks have been widely used by researchers and disaster response agencies. For example, the Social Vulnerability Index (SoVI)[29,30] focuses on socio-economic and demographic factors to identify populations most vulnerable to hazards. While SoVI's simplicity and applicability have made it a staple in vulnerability assessments, it is criticized for insufficiently addressing physical and infrastructural resilience, and for treating vulnerability as a proxy for resilience. Similarly, the Disaster Preparedness Index (DPI)[31,32] emphasizes institutional and social capacities to measure community readiness. However, DPI's focus on pre-disaster preparedness limits its ability to capture adaptive and transformative capacities essential for long-term resilience. Other frameworks, such as the Climate Vulnerability Index (CVI), integrate environmental and hazard exposure data but often lack granularity regarding governance and socio-political dimensions—factors particularly crucial in regions like MENA.

The primary objective of this study is to construct a Disaster Resilience Index (DRI) that builds upon existing approaches while addressing their limitations. The index incorporates socio-economic, institutional, geographical, and natural hazard dimensions into a comprehensive and context-sensitive framework tailored to MENA's unique challenges. By integrating geospatial analytics and regionally specific indicators, the DRI captures the heterogeneous disaster profiles and governance structures of MENA countries. The secondary objective is to examine the relationship between the proposed DRI and disaster losses, thereby highlighting its practical relevance for resilience assessment and policy formulation. This dual focus enhances methodological consistency and aligns the study with international frameworks such as the Sendai Framework for Disaster Risk Reduction and Sustainable Development Goal 13.

Analysis

There are two stages of the analysis: (i) A systematic, and comprehensive disaster resilience index is formed for MENA countries, and (ii) the relation between the disaster resilience index and economic losses is visualized.

Forming disaster resilience index (DRI)

Data

Previous disaster resilience indices were primarily developed for individual countries or subnational regions, such as the United States, Norway, Italy and Korea as presented in Table 1. These frameworks provide valuable insights, but their indicator sets reflect localized priorities, hazard types, and data contexts that are not directly transferable to the diverse MENA region. [1] offers a global resilience index; however, its narrower set of indicators provides limited coverage of MENA-specific challenges.

To address these limitations, the Disaster Resilience Index (DRI) developed in this study incorporates ten core dimensions: Economic, Social, Institutional, Infrastructure, Agricultural, Geographical, Natural Hazard Risk, Emergency Workforce, Women Empowerment, and Human Capital. Each dimension reflects a critical aspect of resilience and is supported by both theoretical foundations and empirical evidence from prior studies, while also responding to the unique characteristics of the MENA region. The current DRI index is composed of 10 dimensions and a total of 76 indicators as discussed below:

Economic resilience

Economic resilience emphasizes financial and economic capacities that enable societies to prepare for and recover from disasters. Wealthier economies with diversified income sources and robust financial systems have greater adaptive capacity. Financial development facilitates investment in mitigation and reconstruction, while foreign exchange reserves enable timely access to technology and capital. This dimension addresses MENA's varied economic structures, ranging from oil-dependent economies to fragile states.

Social resilience

Social resilience incorporates demographic characteristics, social equity, and networks that foster collective action and adaptive capacity. [26]emphasizes the role of civic participation and community structure in post-disaster recovery. The inclusion of indicators reflecting civil society participation and access to social services acknowledges differences within MENA societies, where gender inequalities, and uneven access to services present unique resilience challenges.

Institutional resilience
Institutional resilience encompasses governance quality, regulatory frameworks, and civic freedoms, which collectively influence the effectiveness of disaster preparedness and response. Weak institutional capacities can exacerbate disaster impacts, particularly in fragile states. Governance indicators, combined with measures of civic engagement, capture both formal institutional capacities and broader dimensions of social trust and accountability relevant to the MENA region.

Infrastructure resilience
Infrastructure resilience captures access to essential services such as water, sanitation, energy, and digital communication. As highlighted by[43], infrastructure is vital in maintaining functionality during crises and enabling rapid recovery. Infrastructure is also considered, reflecting the growing importance of digital technologies in early warning systems and disaster coordination[44].

Agricultural resilience
Agricultural resilience is crucial for ensuring food security in disaster-prone contexts, as disruptions to food production can trigger cascading socio-economic effects. While this linkage is globally recognized, it carries particular urgency in the MENA region, where agricultural systems operate under acute constraints of limited arable land, water scarcity, and heightened exposure to climate change. Many rural communities in MENA are highly dependent on agriculture for livelihoods, yet their adaptive capacity is restricted by resource scarcity and institutional limitations.

Geographical resilience
Geographical resilience considers physical accessibility, terrain, and proximity to critical facilities. Geographic variables such as road and railway density, elevation, and proximity to airports capture logistical constraints that influence both exposure and response capacities[35]. These aspects are essential for MENA, where geographic diversity ranges from remote desert regions to densely populated coastal zones.

Natural hazard risk
Natural hazard risk remains a primary determinant of resilience. The MENA region is subject to diverse hazards, including droughts, earthquakes, and extreme heat. A composite hazard risk measure captures differential exposure across countries, addressing a limitation in previous indices that focused on single hazard types.

Emergency workforce
The capacity of the emergency workforce influences the effectiveness of disaster response and recovery. Healthcare capacity, availability of trained personnel, and military readiness are critical in minimizing disaster-related mortality and morbidity. In MENA, disparities in health systems necessitate explicit consideration of this dimension.

Women empowerment
Women's empowerment and gender equity enhance community resilience, as empowered women play vital roles in disaster preparedness, response, and recovery. While gender equity is recognized globally as a driver of resilience, it is especially critical in the MENA context, where persistent gender gaps in economic participation, education, and political representation remain more pronounced than in many other regions. These disparities not only limit women's ability to contribute to disaster risk reduction but also exacerbate household and community vulnerability.

Human capital
Human capital—comprising education, skills, and health—supports long-term adaptive capacity. Populations with higher literacy, better health outcomes, and stronger workforce participation are more likely to recover from shocks and invest in disaster preparedness[45]. This dimension accounts for significant variations in human development across MENA countries.

This selection of dimensions provides a complete and context-sensitive assessment of disaster resilience in the MENA region. Unlike prior indices designed for single-country contexts, the DRI accommodates regional heterogeneity and multi-hazard environments, offering a comprehensive framework for understanding resilience across diverse national settings.

The specifics of the indicators under each dimension, including their units and sources, are detailed in Table 2. The data is the average for the period 2010–2022. Table 3 presents the summary statistics of the indicators used in this study.

All dimensions previously outlined in[1] have been integrated into the present study. Moreover, the dimensions (the digitalization dimension identified in[1] has been integrated with the infrastructure dimension) have been refined through the inclusion of additional explanatory variables that were utilized in other studies, constituting a distinctive contribution to this study. To be precise, an expanded set of indicators were integrated into the DRI calculations, totaling 76, compared to the 62 indicators employed by[1]. The increased number of indicators allows for a more comprehensive assessment of disaster resilience, capturing diverse dimensions that contribute to a country's overall resilience profile. The authors ensured the completeness of their dataset by capturing all relevant variables during the data collection process. As a result, the analysis was not affected by missing data, and no imputation or data omission strategies were required. Additionally, to ensure consistency in interpretation, all indicators were oriented such that higher values reflect greater resilience capacity. Based on theoretical expectations and empirical evidence from PCA loadings, some indicators may be identified as adverse

Dimensions	Indicators	Explanation/unit	Data source	Justification
Economic resilience	Employment, total	%, 15 + population	[46]	[1,35,38]
	Financial depth	%, ratio of broad money to GDP	[46]	[1]
	GDP per capita	constant 2015 US$	[46]	[1,40]
	Total reserves per capita	%, include gold	[46]	[1]
	Trade	%, ratio to GDP	[46]	[1]
	Non-dependence on agriculture	%, population not employed in agriculture	[46]	[1,36,40]
	Commercial bank branches	per 100,000 adults	GSD (2023) [47]	[36]
Social resilience	Civil society participation	0–1	GSD (2023)	[1]
	Power distributed by social group	0–1	GSD (2023)	[1]
	Power distributed by socio-economic position	0–1	GSD (2023)	[1]
	Social class equality in respect for civil liberties	0–1	GSD (2023)	[1]
	Social rights and equality	0–1	GSD (2023)	[1]
	Female	%, ratio to total population	[46]	[34,48]
	Transportation access	%, households with at least one vehicle	[49]	[26]
	Mental health support	facilities per 10,000 persons	[49]	[36]
	Population under 15	%, ratio to total population	[46]	[26]
	Place attachment	Net international migration	[46]	[26]
Institutional resilience	Control of Corruption	− 2.5 to 2.5	WGI (2023) [50]	[1]
	Government Effectiveness	− 2.5 to 2.5	WGI (2023)	[1]
	Political Stability No Violence	− 2.5 to 2.5	WGI (2023)	[1]
	Regulatory Quality	− 2.5 to 2.5	WGI (2023)	[1]
	Rule of Law	− 2.5 to 2.5	WGI (2023)	[1]
	Voice and Accountability	− 2.5 to 2.5	WGI (2023)	[1]
	Freedom of expression	0–1	GSD (2023)	[1]
	Freedom of religion	0–1	GSD (2023)	[1]
	Media freedom	0–1	GSD (2023)	[1]
	Personal integrity and security	0–1	GSD (2023)	[1]
	Access to justice	0–1	GSD (2023)	[37]
	Basic welfare	0–1	GSD (2023)	[37]
	Civil liberties	0–1	GSD (2023)	[37]
	Engaged society	0–1	GSD (2023)	[37]
Infrastructure resilience	Fixed broadband subscriptions	per 100 people	[46]	[1,36]
	Individuals using the internet	% of population	[46]	[1,36]
	Mobile cellular subscriptions	per 100 people	[46]	[1]
	Fixed telephone subscriptions	per 100 people	[46]	[26,38]
	Access to basic drinking water services	% of total	[46]	[1]
	Access to basic sanitation services	% of total	[46]	[1]
	Energy Index	%	[51]	[40]
Agriculture resilience	Access to electricity, rural	% of rural population	[46]	[1]
	Agricultural land	% of land area	[46]	[1]
	Agriculture, forestry, & fishing, value added	% of GDP	[46]	[1]
	Cereal yield	kg per hectare	[46]	[1]
	Employment in agriculture	% of total employment	[46]	[1]
	Food production index	2014–2016 = 100	[46]	[1]
	Livestock production index	2014–2016 = 100	[46]	[1]
	Rural population	% of total population	[46]	[1]
	Rural population growth	annual %	[46]	[1]
Geographical resilience	Total length of roads per sq. km	per square km	[52]	[36,38]
	Total length of railways per sq. km	per square km	[52]	[36]
	Distance from denser settlement areas to airport	km	[52]	[35,36]
	Number of dams	total dam number	[52]	[35]
	Mean elevation of the county	m	[53]	[34,38]
Natural hazard risk	Natural hazard risk index	%	[54]	[38]
Continued				

Dimensions	Indicators	Explanation/unit	Data source	Justification
Emergency workforce	Armed forces personnel	% of total labor force	46	1
	Domestic general govt. health expenditure	% of general govt. expenditure	46	1
	Hospital beds	per 1000 people	46	1,38
	Military expenditure	% of general govt. expenditure	46	1
	Nurses and midwives	per 1000 people	46	1
	Physicians	per 1000 people	46	1,26,36
Women empowerment	Access to justice for women	0–1	47	1
	Employers, female	% of female employment	46	1
	Freedom of discussion for women	0–1	47	1
	Labor force, female	%, ratio to total labor force	46	1,36
	Seats held by women in national parliaments	%	46	1
	Self-employed, female	%, ratio to female employment	46	1
	Gender equality	0–1	47	36
	Labor force participation rate, female	%, ratio to female ages 15 +	46	35
	Literacy rate, adult female	%, ratio to female ages 15 +	46	35
Human capital	Employment	per 100 people	46	1
	Kilocalories per person per day	0–1	47	1
	Life expectancy at birth, total	years	46	1
	Literacy rate	%, ratio to population 15 +	46	1,35
	Population ages 15–64	%, ratio to total population	46	1
	Human Development Index (HDI)	0–1	46	Author contributions
	Compulsory education, duration	years	46	Author contributions
	Government expenditure on education	%, ratio to government expenditure	51	Author contributions

Table 2. Dimensions and indicators of DRI.

and therefore reverse-coded prior to normalization. For example, a higher natural hazard risk index indicates greater exposure to hazards, which can undermine resilience by increasing the likelihood of disaster impacts and diverting resources toward emergency response rather than long-term social and infrastructure development.

Furthermore, this paper introduces two novel dimensions—incorporating geographical resilience and natural hazard risk—into the DRI framework, thereby augmenting its comprehensiveness. This strategic inclusion serves as an additional scholarly contribution. Geographical resilience is evaluated based on five indicators, and their values are determined through calculations within the GIS, with the assistance of ArcGIS. Illustration in Fig. 1 is an example involving the computation of distances from densely populated settlement areas to the nearest airports. This process involves two main steps: firstly, the calculation of Euclidean distances—the straight-line distance between two points in Euclidean space—from each airport within a country; and secondly, the identification of the furthest settlement area from the airports using land cover obtained from the Sentinel 2 satellite. The length of roads and railways are also determined using GIS.

Index construction steps

This research employed the IMF's index creation process as in[1], which involves winsorization of the chosen variables, normalization of the winsorized variables, estimation of Principal Component Analysis (PCA) weights for the normalized variables, and the development of the disaster resilience index using the determined PCA weights[56,57].

Winsorization Winsorization is a data transformation technique that limits extreme values in the dataset to reduce the effect of potentially misleading outliers. Winsorization involves adjusting statistical data by limiting extreme values, effectively reducing the impact of potentially misleading outliers. In this study, the 5th and 95th percentiles are employed as cut-off values to exclude outliers[57].

While extreme values can contain meaningful information, especially in disaster resilience contexts, uniform winsorization at the 5–95% range has been widely adopted in index construction literature to improve robustness and comparability across indicators[1,56]. Given the cross-country scope of this study and the presence of diverse scales and measurement units, this approach helps mitigate the disproportionate influence of a few extreme observations without entirely removing them.

Moreover, since the final Disaster Resilience Index is constructed using PCA, which assigns weights based on underlying variance structures, the effect of any remaining outliers is further diluted during aggregation. Thus, the application of winsorization is intended as a conservative preprocessing step to preserve the relative variation among countries while minimizing distortion from anomalies. The summary statistics of indicators before and after winsorization can be found in Table A2 in Appendix.

Normalization To ensure comparability across indicators, all variables were rescaled to a 0–1 range using min–max normalization. Min–max normalization is sensitive to outliers; however, by applying winsorization prior to this step, the influence of extreme values is already moderated. Among the available methods, we

Dimensions	Indicators	Mean	Std. Dev	Min	Max
Economic resilience	Employment, total	48.12	16.82	23.63	86.90
	Financial depth	82.23	42.37	33.17	245.78
	GDP per capita	14,665.00	16,412.76	979.47	65,612.73
	Total reserves per capita	4,860.56	5,592.04	106.32	17,189.55
	Trade	99.82	71.22	39.01	309.94
	Non-dependence on agriculture	11.25	10.57	1.06	37.17
	Commercial bank branches	13.71	8.57	1.73	33.52
Social resilience	Civil society participation	0.48	0.13	0.25	0.76
	Power distributed by social group	0.47	0.18	0.13	0.76
	Power distributed by socio-economic position	0.46	0.17	0.18	0.76
	Social class equality in respect for civil liberties	0.56	0.16	0.21	0.81
	Social rights and equality	0.39	0.13	0.08	0.68
	Female	45.78	7.31	25.68	50.75
	Transportation access	280.96	200.34	40.00	786.00
	Mental health support	0.05	0.05	0.01	0.19
	Population under 15	27.80	8.26	13.77	41.63
	Place attachment	5,078	108,168	− 383,981	176,830
Institutional resilience	Control of Corruption	− 0.29	0.78	− 1.47	1.09
	Government Effectiveness	− 0.19	0.85	− 1.70	1.28
	Political Stability No Violence	− 0.82	1.08	− 2.62	1.10
	Regulatory Quality	− 0.23	0.90	− 1.90	1.23
	Rule of Law	− 0.26	0.85	− 1.67	1.14
	Voice and Accountability	− 0.89	0.73	− 1.88	1.15
	Freedom of expression	22	0.41	0.12	0.14
	Freedom of religion	22	0.40	0.12	0.18
	Media freedom	0.22	0.32	0.00	1.00
	Personal integrity and security	0.39	0.13	0.15	0.70
	Access to justice	0.53	0.15	0.21	0.77
	Basic welfare	0.62	0.11	0.38	0.83
	Civil liberties	0.47	0.13	0.21	0.80
	Engaged society	0.50	0.15	0.18	0.78
Infrastructure resilience	Fixed broadband subscriptions	− 0.82	1.08	− 2.62	1.10
	Individuals using the internet	55.66	23.34	14.71	88.22
	Mobile cellular subscriptions	111.23	39.44	30.01	184.48
	Fixed telephone subscriptions	16.54	12.59	2.58	52.59
	Access to basic drinking water services	93.18	10.48	55.68	100.00
	Access to basic sanitation services	91.37	12.34	51.82	100.00
	Energy Index	68.14	16.22	16.00	84.00
Agriculture resilience	Access to electricity, rural	89.27	23.43	17.34	100.00
	Agricultural land	35.16	27.85	3.77	80.72
	Agriculture, forestry, & fishing, value added	6.07	6.73	0.17	29.33
	Cereal yield	4,523.39	5,507.71	665.32	24,799.58
	Employment in agriculture	11.38	10.62	1.07	37.44
	Food production index	100.79	8.00	87.84	119.38
	Livestock production index	99.73	7.78	86.48	122.42
	Rural population	23.54	16.90	0.00	64.89
	Rural population growth	0.16	1.20	− 2.69	2.43
Geographical resilience	Total length of roads per sq. km	0.94	2.29	0.05	9.80
	Total length of railways per sq. km	0.03	0.05	0.00	0.18
	Distance from denser sett. areas to airport	165.32	170.67	10.00	690.00
	Number of dams	137.05	195.86	0.00	588.00
	Mean elevation of the county	424.77	362.65	14.00	1305.00
Natural hazard risk	Natural hazard risk index	9.13	6.52	0.94	24.26
Continued					

Dimensions	Indicators	Mean	Std. Dev	Min	Max
Emergency workforce	Armed forces personnel	2.88	1.77	0.93	6.24
	Domestic general govt. health expenditure	8.85	3.83	3.27	18.53
	Hospital beds	1.98	0.94	0.71	4.62
	Military expenditure	12.34	5.39	1.35	25.72
	Nurses and midwives	3.33	2.06	0.73	7.65
	Physicians	1.72	0.83	0.22	3.51
Women empowerment	Access to justice for women	0.53	0.15	0.27	0.79
	Employers, female	1.51	0.70	0.31	2.84
	Freedom of discussion for women	0.46	0.15	0.12	0.73
	Labor force, female	22.90	9.01	9.71	46.87
	Seats held by women in national parliaments	13.41	8.04	0.33	27.86
	Self-employed, female	23.63	22.29	0.40	68.58
	Gender equality	0.40	0.14	0.15	0.70
	Labor force participation rate, female	28.14	14.82	7.46	58.35
	Literacy rate, adult female	81.12	16.82	35.00	98.20
Human capital	Employment	47.55	16.02	24.05	85.56
	Kilocalories per person per day	0.52	0.19	0.22	0.83
	Life expectancy at birth, total	74.11	5.04	60.68	81.59
	Literacy rate	84.95	12.00	54.10	96.00
	Population ages 15–64	66.45	8.04	53.98	83.76
	Human Development Index (HDI)	0.65	0.14	0.31	0.86
	Compulsory education, duration	9.46	1.25	6.00	13.00
	Government expenditure on education	14.24	5.14	4.70	25.45

Table 3. Summary statistics.

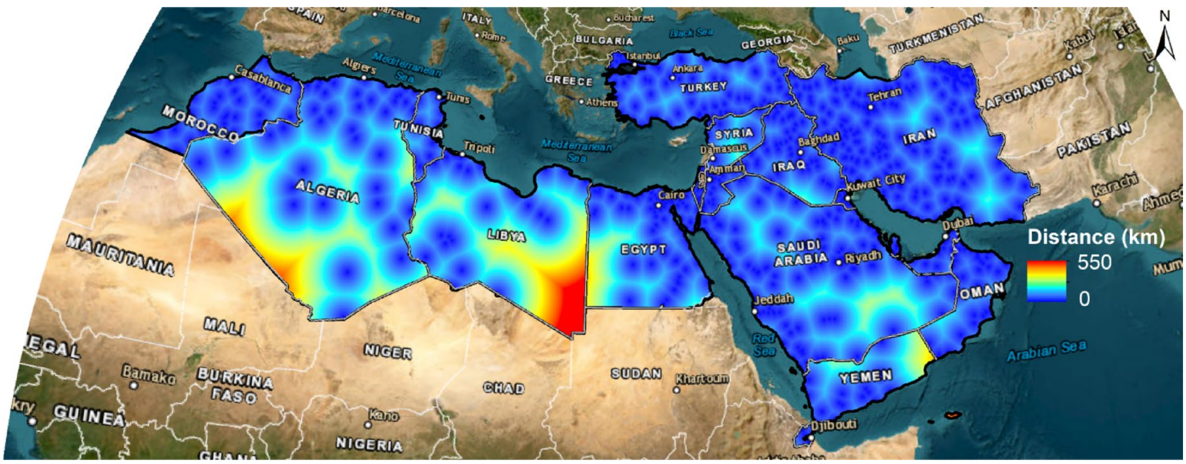

Fig. 1. Euclidean distance from airports for each MENA country (generated using ArcMap 10.8.1[55]).

adopt min–max normalization rather than z-score standardization for two main reasons. First, min–max normalization preserves the original distribution and relative differences between countries while rescaling indicators into a uniform 0–1 range, which enhances interpretability of resilience scores and facilitates direct comparison across dimensions. In contrast, z-score standardization centers variables around zero and expresses them in terms of standard deviations, which can obscure the practical meaning of values in a policy-oriented index. Second, since winsorization is applied beforehand, the distortive effect of extreme outliers on min–max scaling is already mitigated, ensuring that rescaled values remain representative of the meaningful range of variation across countries. This two-step approach ensures that the scaling reflects meaningful variation across countries without being compressed by isolated extremes. Furthermore, the consistency of this method across all indicators improves comparability and supports the structure of PCA, which assumes variables are measured on comparable scales.

Compound index Compound indices simplify complex data by combining multiple variables into a single measure. Through the assignment of suitable weights, these indices accurately reflect the importance of each variable within the broader concept. To derive a compound index, the data is first normalized, and then PCA weights for each indicator are calculated. PCA is a statistical technique that identifies the fundamental factors or components influencing the variability in a dataset. Once the weights for each indicator are determined, the next step involves multiplying these weights by the corresponding values of the normalized indicators. The results for each indicator are then summed, yielding the final disaster risk index for each country. This process combines the weighted contributions of various indicators to provide a comprehensive assessment of disaster risk for each specific country. The following equation presents the calculation of the disaster resilience indices of each country.

$$DRI_i = \sum_{i=1}^{N} w_i x_{norm,i} \tag{1}$$

where DRI_i is the disaster resilience index for a country and w is the weight calculated from the PCA analysis[57].

PCA-derived weights are used in this study due to their empirical and data-driven nature, which avoids subjective bias in assigning importance to indicators. This method has been widely adopted in composite index construction, a single metric derived from aggregating multiple indicators—including financial development indices[56] and resilience indices[1] —as it reflects the latent structure of the data and ensures internal consistency.

We acknowledge that high variance does not always imply higher policy relevance; some critical indicators may indeed show limited variation across countries. To address this concern, all indicators were retained in the framework regardless of their variance contribution, ensuring that dimensions with strong policy importance (e.g., governance or gender equity) are not excluded or overlooked. Although PCA assigns smaller weights to low-variance indicators, their inclusion in the index preserves their influence and visibility in resilience assessments. PCA is particularly effective in a comparative, cross-country framework, where the objective is to summarize multidimensional information into fewer dimensions while preserving as much of the variation as possible. Importantly, PCA enables dimensionality reduction while controlling multicollinearity, which would otherwise skew the index if indicators were simply averaged.

To ensure the robustness of the PCA-based weighting, the explained variance ratios for the principal components were computed and discussed in the Results Section.

The relation between the DRI and the disaster loss

Resilient communities have taken proactive measures to decrease their susceptibility to disasters and enhance their ability to adapt and respond to them, aiming to minimize the negative consequences and harm caused by such events. Therefore, an increase in disaster resilience would lead to a decrease in losses arising from disasters.

The disaster loss data for the period 2010–2022 is taken from the EM-DAT database (2023). Although there are other variables indicating the loss such as total affected persons and total economic damage due to the disasters in the database, there are missing observations for these indicators. We have total death data for 77% of the disasters occurred in the 22 countries in our sample for 2010–2022 period.

The disaster types covered in this study are earthquake, epidemic flood, extreme temperatures, landslide, storm and wildfires. Figure 2 presents the number of disasters and the total deaths in MENA countries for 2010–2022 period by disaster type. While the disaster type that occurs frequently in the region is flooding, earthquakes cause the highest number of deaths in MENA[57].

The countries in the MENA region faced with frequent disasters during 2010–2022 period as shown in Fig. 3. While Iran is the country that faced with the highest number of disasters, Yemen has the highest number of fatalities due to disasters.

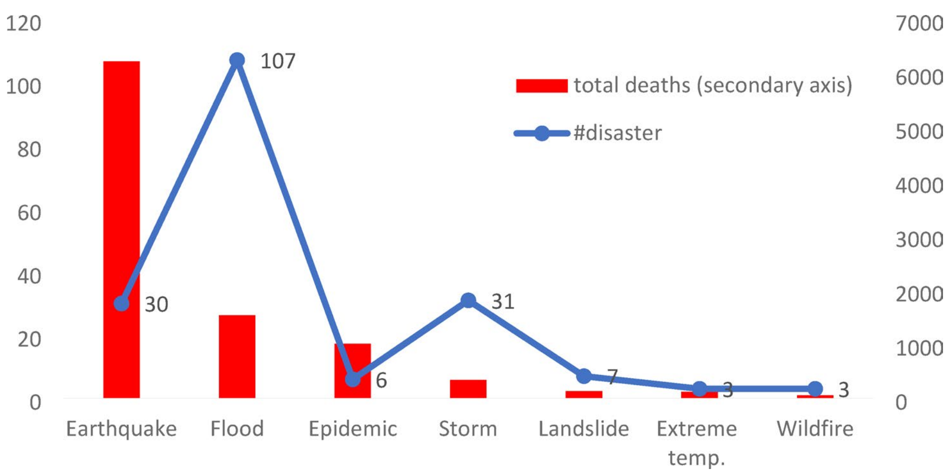

Fig. 2. Number of disasters and total deaths in MENA for 2010–2022, by disaster type.

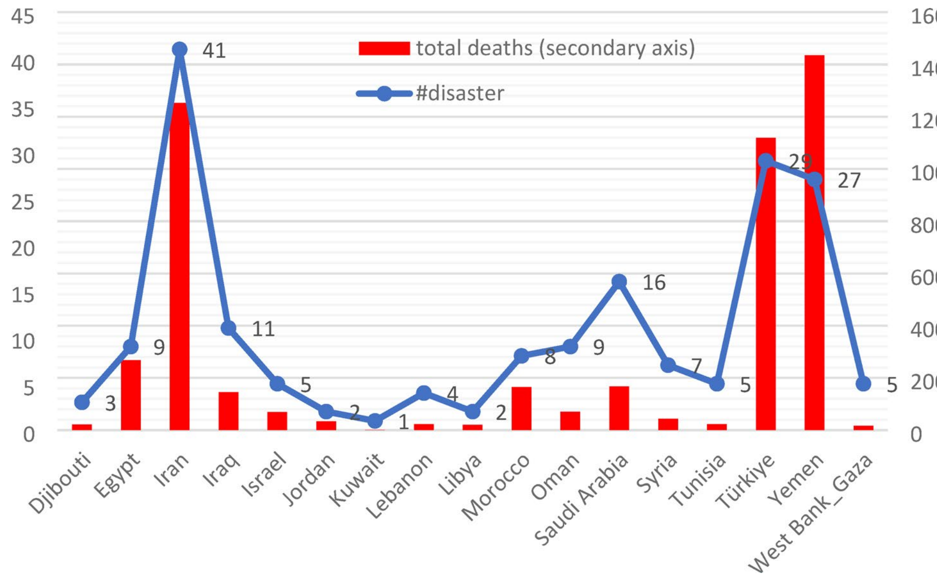

Fig. 3. Number of disasters and total deaths in MENA for 2010–2022, by country.

The relation between the disaster resilience index and disaster loss is analyzed using correlation graphics and visualized using the scatter diagrams. Due to the limited number of countries further estimation techniques are not utilized.

Furthermore, to assess the internal relationships among the ten dimensions of the DRI, a correlation analysis is performed. This analysis serves a dual purpose: first, to examine the degree of interdependence between dimensions, identifying potential overlaps or redundancies; and second, to ensure that each dimension captures a distinct aspect of disaster resilience. Such analyses are commonly employed in resilience studies to validate the multidimensional structure of composite indices[20,37].

Results and discussion

In this study, as a first stage, ten dimensions of DRI are calculated using the PCA of the relevant variables as presented in Table 4 (Weights of each variable is presented in Table A1). As a second stage, the DRI for MENA countries are calculated from the 10 dimensions from the first stage utilizing principal component analysis. To clearly justify the use of PCA in this study, the explained variance by principal components is shown in Fig. 4. The first principal component alone explains approximately 36% of the total variance. The cumulative explained variance increases sharply with the first few components: over 50% is captured by the first 3 components, and more than 70% by the first 7 components. Notably, the first 10 components account for roughly 84% of the total variance, and over 95% is explained by the first 17 components. The curve levels off after this point. While a relatively small number of components captures the majority of variance, we include all 76 indices in the analysis to ensure that all dimensions of disaster resilience are fully represented, and that no potentially relevant information is omitted. Including the complete set of indicators preserves the richness of the multidimensional dataset, allows the DRI to reflect subtle variations across countries, and maintains transparency in indicator selection. PCA thus serves both to aggregate and to weight the indicators appropriately, while retaining the overall informational structure of the data, enhancing the index's robustness and interpretability.

The DRI and ten dimensions of DRI are presented in Table 4 for 22 MENA countries, whereas Fig. 5 visually demonstrates DRI with categories of five distinct ranges of the Disaster Resilience Index.

The DRI for MENA countries reveals a diverse spectrum of preparedness and resilience. Looking at the high end, some smaller countries like Malta, Israel, Qatar and Kuwait showcase a high level of preparedness and resilience in the face of potential disasters. Among these countries, although Qatar has the highest economic resilience and human capital resilience, DRI of Qatar ranks the third. While Malta has much lower economic resilience compared to Qatar, Malta has top ranking in infrastructure, institutional and emergency workforce resilience. It is important to emphasize that Qatar and Malta are the two countries with low natural hazard risk, as well[57].

The correlation matrix for DRI dimensions is provided in Table 5. The results reveal several notable patterns. Strong positive correlations were observed between Economic Resilience and Human Capital ($r = 0.854$, $p < 0.05$), Institutional Resilience and Women Empowerment ($r = 0.919$, $p < 0.05$), and Infrastructure Resilience and Emergency Workforce ($r = 0.773$, $p < 0.05$). These associations likely reflect shared underlying drivers, such as socio-economic development, governance capacity, and investment in human resources. Conversely, strong negative correlations emerged between Economic Resilience and Agriculture Resilience ($r = -0.825$, $p < 0.05$), as well as between Human Capital and Agriculture Resilience ($r = -0.8838$, $p < 0.05$). These inverse relationships may indicate a structural trade-off, where countries heavily reliant on agriculture exhibit lower levels of economic diversification and human capital accumulation. Several dimensions, such as Social Resilience and

Country	DRI	Natural hazard risk	Economic	Social	Human capital	Agriculture	Emergency workforce	Institutional	Women empowerment	Infrastructure	Geographical
Algeria	0.452	0.424	0.271	0.620	0.457	0.373	0.405	0.421	0.528	0.449	0.719
Bahrain	0.632	0.084	0.549	0.139	0.781	0.166	0.372	0.450	0.533	0.699	0.031
Djibouti	0.257	0.466	0.290	0.502	0.101	0.781	0.054	0.353	0.338	0.244	0.412
Egypt, Arab R	0.300	0.860	0.131	0.352	0.390	0.555	0.298	0.378	0.353	0.491	0.479
Iran, Islamic R	0.351	0.774	0.215	0.513	0.507	0.424	0.433	0.310	0.323	0.569	0.969
Iraq	0.322	0.387	0.165	0.509	0.280	0.585	0.185	0.255	0.402	0.414	0.457
Israel	0.836	0.229	0.709	0.784	0.709	0.267	0.639	0.836	0.937	0.833	0.409
Jordan	0.566	0.183	0.303	0.595	0.571	0.230	0.403	0.544	0.589	0.521	0.544
Kuwait	0.711	0.147	0.661	0.545	0.778	0.091	0.702	0.559	0.657	0.621	0.348
Lebanon	0.576	0.185	0.487	0.596	0.599	0.433	0.425	0.488	0.522	0.532	0.593
Libya	0.442	0.610	0.443	0.659	0.591	0.534	0.745	0.242	0.463	0.474	0.628
Malta	0.908	0.083	0.549	0.847	0.768	0.288	0.946	0.908	0.827	0.908	0.130
Morocco	0.384	0.452	0.108	0.634	0.401	0.776	0.264	0.501	0.467	0.465	0.549
Oman	0.572	0.333	0.493	0.435	0.702	0.197	0.484	0.548	0.511	0.587	0.502
Qatar	0.744	0.092	0.933	0.085	0.899	0.103	0.651	0.625	0.616	0.669	0.160
Saudi Arabia	0.494	0.426	0.646	0.327	0.670	0.576	0.606	0.393	0.452	0.644	0.802
Syrian Arab R	0.238	0.525	0.205	0.254	0.388	0.909	0.232	0.092	0.360	0.434	0.581
Tunisia	0.545	0.435	0.230	0.915	0.548	0.586	0.494	0.592	0.648	0.529	0.453
Turkiye	0.463	0.686	0.239	0.631	0.611	0.531	0.517	0.488	0.508	0.603	0.775
UAE	0.691	0.303	0.738	0.182	0.858	0.107	0.541	0.619	0.666	0.774	0.478
West Bank_Gaza	0.472	0.243	0.219	0.656	0.443	0.663	0.280	0.459	0.543	0.460	0.355
Yemen, R	0.044	0.917	0.067	0.318	0.165	0.840	0.219	0.154	0.063	0.092	0.757

Table 4. The sub-indices score for MENA countries.

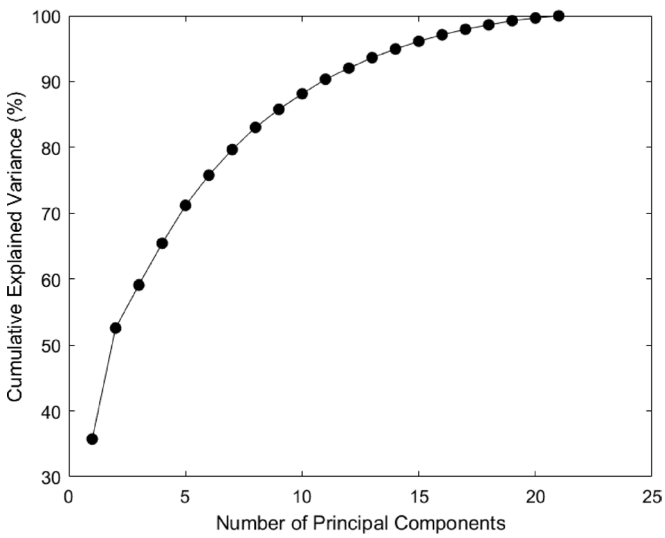

Fig. 4. The explained variance by principal components.

Geographical Resilience, displayed weak correlations with most others (e.g., r = 0.013 between Geographical and Social Resilience), suggesting they capture unique and complementary aspects of disaster resilience. While the correlation matrix revealed several strong associations between dimensions, these patterns primarily reflect underlying socio-economic linkages rather than redundancy in measurement. Disaster resilience is inherently multidimensional, and dimensions such as Social Resilience or Geographical Resilience showed weak or distinct correlations with most others, highlighting their unique contributions. Reducing the number of indicators based solely on correlation risks overlooking these complementary aspects. Instead of eliminating dimensions, our approach retains them to preserve the conceptual breadth of the DRI, while acknowledging that some correlations are expected due to shared structural drivers such as governance capacity, investment in human resources, and economic diversification. Additionally, the suitability of PCA for the indices was supported by a

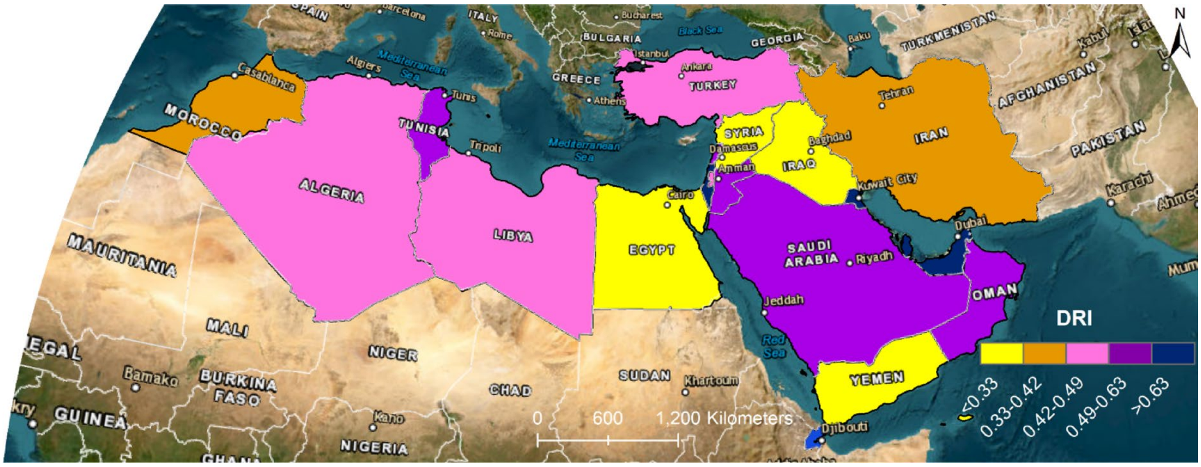

Fig. 5. Disaster resilience index of MENA countries (generated using ArcMap 10.8.1[55]).

	Economic resilience	Social resilience	Institutional resilience	Infrastructure resilience	Agriculture resilience	Geographical resilience	Natural hazard risk	Emergency workforce	Women empowerment	Human capital
Economic resilience	1									
Social resilience	−0.141	1								
Institutional resilience	0.569*	0.586*	1							
Infrastructure resilience	0.678*	0.231	0.703*	1						
Agriculture resilience	−0.825*	−0.021	−0.646*	−0.739*	1					
Geographical resilience	−0.520*	0.013	−0.500*	−0.308	0.3799	1				
Natural hazard risk	−0.699*	−0.163	−0.634*	−0.593*	0.6779*	0.745*	1			
Emergency workforce	0.649*	0.465*	0.682*	0.773*	−0.6275*	−0.204	−0.468*	1		
Women empowerment	0.505*	0.671*	0.919*	0.723*	−0.5440*	−0.466*	−0.653*	0.695*	1	
Human capital	0.854*	0.033	0.625*	0.872*	−0.8838*	−0.354	−0.629*	0.783*	0.588*	1

Table 5. The correlation matrix for the sub-indices of DRI. Table shows Pearson correlation coefficients. *p-value < 0.05.

Kaiser–Meyer–Olkin (KMO) measure of 0.664 and a significant Bartlett's test of sphericity ($\chi2 = 224.62$, df = 45, $p < 0.001$), indicating adequate sampling adequacy and sufficient correlations among the variables.

This pattern of results aligns well with existing knowledge of disaster preparedness and governance capacity in the MENA region, substantiating the reliability of the DRI. Countries such as Malta, Israel, Qatar, and Kuwait score highly not only due to their robust infrastructure and strong economic resources but also because of their relatively low exposure to natural hazards and well-established governance systems. These findings are consistent with previous research emphasizing the role of institutional quality and human capital in disaster resilience[1,26]. Moreover, sub-index analysis reveals that high-performing countries tend to exhibit balanced strengths across most dimensions, particularly in institutional resilience, infrastructure, and emergency workforce capacity. This multidimensional strength supports the conceptual validity of the DRI by demonstrating that resilience is not driven by a single factor but emerges from the interaction of economic, social, and institutional capacities.

The countries facing significant challenges in terms of disaster resilience according to the DRI are Yemen, the Syrian Arab Republic, Djibouti, Egypt and Iraq. A low score suggests a critical need for enhanced disaster preparedness, response, and recovery measures in the country. For many countries in the region, DRIs fall within a moderate range, indicating a reasonably balanced approach to disaster resilience[57].

Additionally, Fig. 6 presents the DRI scores for the classified country groups within the MENA region. The DRI results show significant variation among MENA country groups. The Gulf Cooperation Council (GCC) countries group scores the highest (0.641), reflecting strong institutional frameworks, economic capacity, and infrastructure investments that enhance resilience. In contrast, Conflict-Affected States have the lowest DRI score (0.304), indicating severe vulnerability due to fragile governance, insecurity, and limited disaster management capacity. North African States fall in the mid-range (0.420), suggesting moderate resilience with room for improvement, particularly in institutional readiness and socioeconomic equity. The "Others" group—including Türkiye, Iran, Israel, and Malta—records a relatively high average DRI (0.565), highlighting a more favorable resilience profile, though still behind the GCC.

The findings of this study provide important insights for policymakers and practitioners seeking to strengthen disaster resilience in the MENA region. The sub-index analysis highlights significant differences

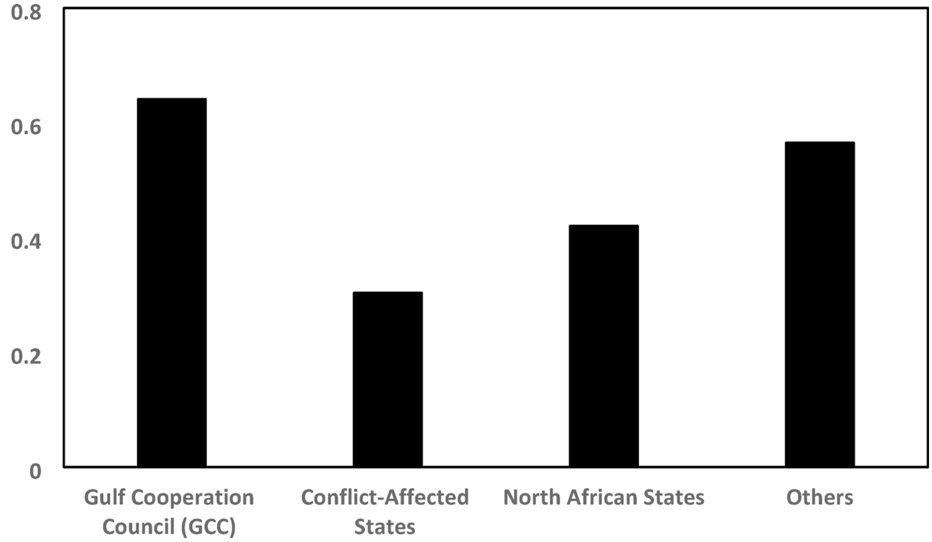

Fig. 6. Disaster resilience index of MENA countries by group Gulf Cooperation Council (GCC): Saudi Arabia, Bahrain, UAE, Qatar, Kuwait, Oman; Conflict-Affected States: Iraq, Syrian Arab R., Libya, Yemen, R., West Bank_Gaza; North African States: Algeria, Morocco, Egypt, Arab R., Tunisia; Others: Djibouti, Iran, Islamic R., Israel, Türkiye, Jordan, Lebanon, Malta.

across countries and dimensions, emphasizing the need for tailored policy interventions. For low-performing countries, particular emphasis should be placed on enhancing institutional capacity, strengthening governance structures, and improving transparency and accountability. These measures align with Priority 2 of the Sendai Framework, which emphasizes strengthening disaster risk governance to manage disaster risk effectively.

Investments in critical infrastructure, including health systems, transport networks, and communication technologies, are also essential to address vulnerabilities identified in the infrastructure and emergency workforce dimensions. Such investments support Priority 3 of the Sendai Framework, which supports investing in disaster risk reduction for resilience. Additionally, advancing social inclusion and gender equity is essential for building community-level adaptive capacity, particularly in countries where social and gender disparities worsen vulnerability. This aligns with Priority 4 of the Sendai Framework, which focuses on enhancing disaster preparedness for effective response and building back better in recovery.

National adaptation planning strategies should incorporate these priorities by integrating multi-dimensional resilience assessments into development planning. This approach confirms that resilience-building efforts address the interlinked economic, social, and environmental challenges faced by MENA countries. Strengthening collaboration with international organizations to collect and standardize data on disaster management systems would further enhance the capacity of policymakers to design evidence-based interventions.

Comparison of DRI with previous studies

The present study offers a valuable extension and refinement of the DRI calculations previously conducted by[1]. One notable distinction is the broader scope of our study, which successfully calculates DRI values for a more extensive list of MENA countries, addressing the data limitations that[1] faced. While[1] could only calculate DRI values for a limited set of countries in MENA region, our study encompasses a more comprehensive coverage.

The comparative analysis presented in Fig. 7 showcases DRI values for the common countries, namely Algeria, Egypt, Jordan, Morocco, Tunisia, and Türkiye, covered in both studies. Despite the differences in the indicators used and the variation in the number of countries, the DRI values calculated in the present study and those from[1] exhibit a notable degree of similarity. This suggests a robustness and consistency in the assessment of disaster resilience, even when accounting for variations in data availability and methodological approaches.

The divergences between the two studies can largely be attributed to differences in indicator selection, the inclusion of newly available socio-economic and institutional dimensions, and the application of PCA-based weighting in our framework. While[1] relied on a smaller set of indicators and equal weighting, our approach integrates a broader set of resilience drivers and assigns weights empirically through PCA, which captures the underlying data structure. The overall alignment of DRI values, therefore, underscores the reliability of the findings. Significant disparities in DRI values between the two studies are particularly notable in the cases of Egypt and Jordan, where differences of approximately 20% are observed. In contrast, for the remaining countries, the variation in DRI values is less pronounced, consistently falling below 7 percent. This indicates that while the overall DRI values show a general alignment between the two studies, Egypt and Jordan stand out as instances where the assessments diverge more substantially. These higher differences highlight the importance of the augmentation in this study because of new dimensions and indicators that carry essential information regarding disaster resilience.

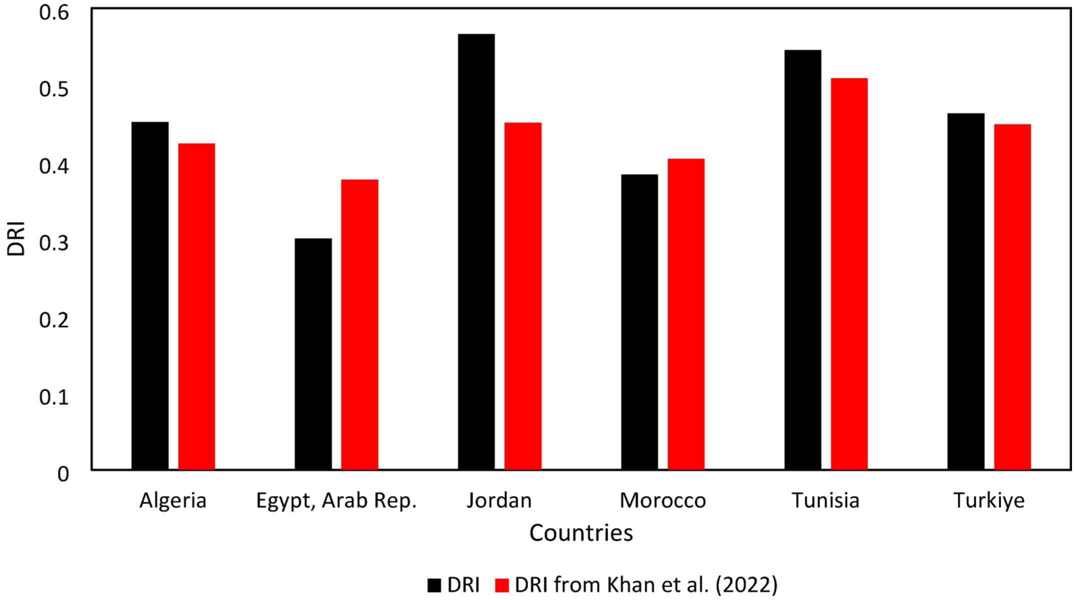

Fig. 7. The comparative analysis of the DRI values for previously calculated countries.

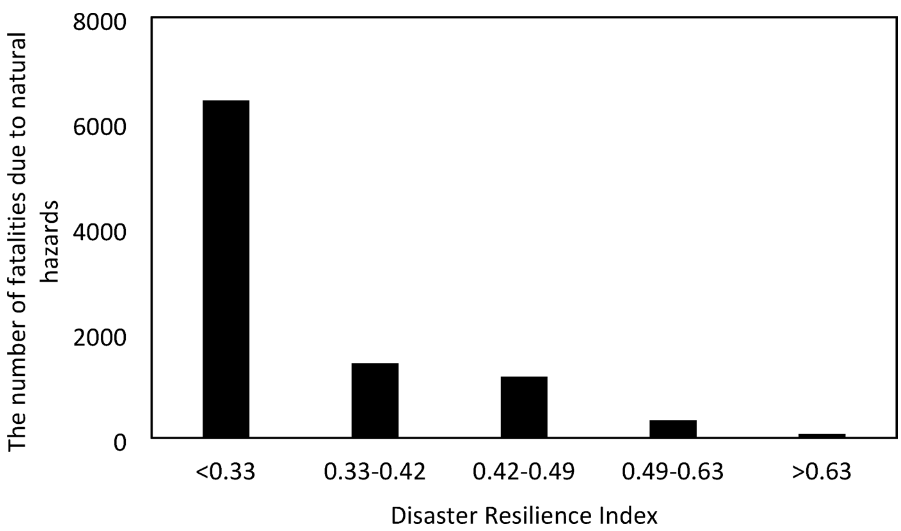

Fig. 8. The effects of disaster resilience on the number of fatalities due to disasters.

Validation of DRI

Figure 8 illustrates the relationship between the DRI, and the fatalities caused by natural hazards. The data, sourced from the EM-DAT database (2023), encompasses natural hazard events occurring between 2010 and 2022. The figure indicates a clear inverse correlation between the DRI and total deaths resulting from natural hazards. The increase in the index reflects a higher level of resilience coinciding with a noticeable decrease in the number of fatalities, aligning with expectations. This observed inverse correlation serves as compelling evidence supporting the soundness of the methodology employed in the study.

Sensitivity analysis

In this study DRI is calculated by using two methods. The first approach, whose results are presented above, involves conducting PCA separately for each dimension, followed by aggregating the results to obtain the final DRI. The second method directly applies PCA to all indicators collectively, bypassing the intermediate step of dimension-specific PCA.

Figure 9 illustrates the DRI values for each country under the two distinct approaches, dimension-specific PCA and PCA for all indicators. Notably, the values obtained through these approaches are closely aligned, suggesting a consistent representation of disaster resilience regardless of whether PCA is applied separately to dimensions or collectively to all indicators.

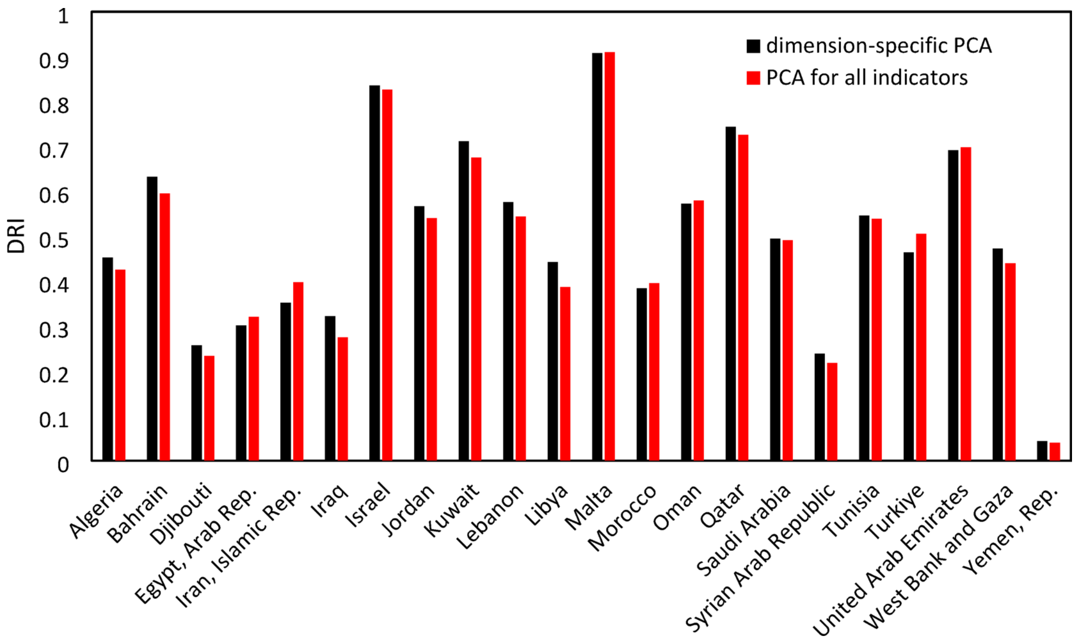

Fig. 9. The sensitivity analysis.

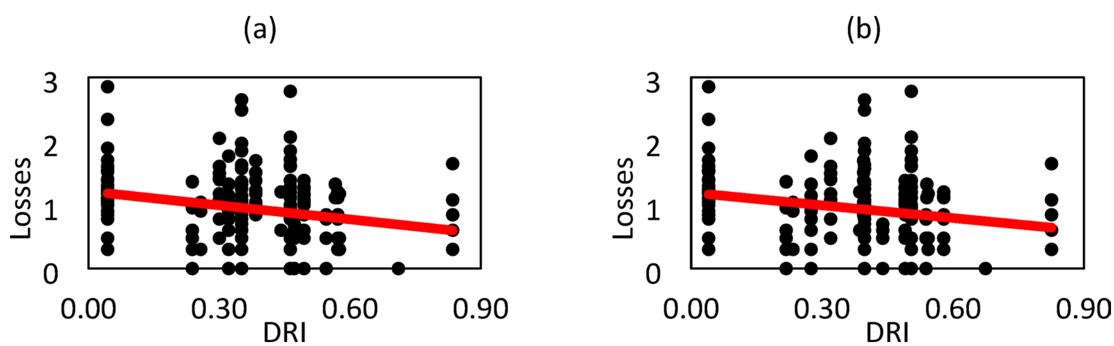

Fig. 10. Scatter diagram for different calculations of DRI and losses. *Note*: Losses is the logarithmic form of the number of fatalities due to natural hazards. (**a**) dimension-specific PCA and (**b**) PCA for all indicators.

Upon examining the figure, it is evident that the DRI values for each country exhibit minimal divergence between the approaches. For instance, countries like Malta, with high DRI values in both methods, demonstrate a robust level of disaster resilience. Similarly, Yemen, Rep. exhibits lower DRI values in both approaches, indicating comparatively lower resilience. The marginal differences between the two approaches suggest that the choice of conducting PCA at the dimension level does not significantly alter the overall assessment of disaster resilience.

Finally, we compared the relation between DRI and total deaths due to disasters for the two different constructions of DRI. Figure 10 presents scatter diagrams, where panel (a) is for dimension-specific PCA used in the previous sections, and panel (b) is for PCA for all indicators. Both panels show a negative relation between the number of fatalities due to disasters and DRI. To ensure statistical robustness, we complemented the OLS regression with heteroskedasticity diagnostics and robust inference for dimension-specific PCA. The Breusch–Pagan test (LM statistic = 0.120, p-value = 0.73) shows no evidence of heteroskedasticity, indicating that the variance of residuals is constant. Consequently, while White's heteroskedasticity-robust standard errors (intercept: 0.091, slope: 0.21) are reported, the standard OLS results are likely reliable. The OLS regression results show an intercept of 1.214 (95% CI 1.03, 1.40), a slope of -0.735 (95% CI -1.19, -0.28), an F-statistic of 10.34, and a p-value of 0.0015, indicating a statistically significant model with a negative relationship between DRI and fatalities. The estimated slope coefficient remains statistically significant, suggesting a robust negative relationship between the DRI and disaster-related fatalities. The figure indicates a clear inverse correlation between the DRI and total deaths resulting from natural hazards. The increase in the index reflects a higher level of resilience coinciding with a noticeable decrease in the number of fatalities, aligning with expectations. This observed inverse correlation serves as compelling evidence supporting the soundness of the methodology employed in the study.

This study has several limitations that suggest directions for future research. The analysis relies on EM-DAT data, which provides a comprehensive record of disaster-related fatalities but lacks consistent and complete information on financial losses for many disasters in the MENA region. As a result, the study uses fatalities as a proxy for disaster impact, which captures an important dimension of vulnerability and recovery but does not fully reflect the broader economic consequences of disasters. The analysis also does not account for differences in disaster intensity, which may affect the comparability of resilience across countries. Moreover, the DRI was developed using national-level data, which may obscure subnational variations in resilience, particularly in countries with significant regional disparities. Finally, the absence of standardized, cross-country data on national disaster management systems, including governance structures, preparedness, and institutional capacities, represents an important limitation. Such data would significantly enhance the DRI's ability to assess resilience comprehensively. Future research could address these gaps by integrating subnational and higher-resolution datasets, incorporating measures of disaster magnitude and intensity, and utilizing more complete financial loss data. Coordinated international efforts to gather and harmonize data on disaster management systems would further strengthen resilience assessments and provide a more nuanced understanding of countries' adaptive capacities.

Conclusions and policy implications

This study introduces a novel and comprehensive DRI tailored specifically for the MENA countries, addressing a critical need for region-specific disaster preparedness and resilience assessment. The DRI incorporates 10 dimensions and 76 indicators, capturing economic, social, institutional, infrastructure, agricultural, geographical, natural hazard risk, emergency workforce, women empowerment, and human capital resilience. Notably, this index extends beyond existing frameworks by integrating geospatial data on disaster risk from GIS, incorporating the natural hazard risk index, and establishing a correlation between the DRI and economic losses.

The findings reveal a diverse landscape of disaster resilience in the MENA region, with some countries demonstrating high preparedness and resilience, while others face significant challenges. The classification of the DRI enables a detailed comprehension of the strengths and vulnerabilities of the region concerning its capacity to withstand and recover from disasters. The inclusion of novel dimensions such as geographical resilience and natural hazard risk also provides a more holistic perspective for policymakers, practitioners, and researchers. Analysis of dimension-specific scores indicates that low-performing countries—such as Yemen, Djibouti, and Egypt—exhibit pronounced weaknesses in institutional capacity, human capital, and emergency workforce readiness, while their infrastructure and economic dimensions are relatively better.

Furthermore, the study establishes a clear inverse correlation between the DRI and total deaths resulting from natural hazards. As the index increases, indicating a higher level of resilience, there is a discernible decrease in the number of fatalities. This correlation supports the efficacy and robustness of the DRI methodology, reinforcing the importance of comprehensive resilience assessment in minimizing the impact of natural disasters.

Additionally, repeating the calculation of the DRI using dimension-specific PCA and PCA for all indicators reveals closely aligned DRI values, indicating a consistent representation of disaster resilience. The slight variations observed between the two approaches indicate that conducting PCA at the dimension level does not substantially change the overall evaluation of disaster resilience.

Policymakers in the MENA region can utilize the DRI to prioritize interventions and allocate resources effectively. Countries with lower DRI scores may benefit from targeted investments in disaster preparedness, response, and recovery mechanisms. The findings suggest that low-performing MENA countries should prioritize strengthening institutional capacity, human capital development, and emergency workforce readiness as immediate interventions, before investing in other dimensions such as infrastructure or economic capacity. Targeted training, governance reforms, and capacity-building programs can provide the most immediate improvement in overall resilience. Additionally, implementing policies aligned with the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goal 13 can further enhance disaster resilience and reduce associated losses.

Finally, this study has several limitations that should be acknowledged. While PCA provides an empirical weighting approach, it may underrepresent low-variance but policy-relevant indicators. Additionally, the DRI reflects relative resilience and does not capture all contextual factors, such as political instability or sudden conflict events, which may influence disaster outcomes. Future studies could integrate dynamic and real-time data to refine the index further.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Declarations

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